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Solar-System Tests of Gravitational Theories

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We are engaged in testing gravitational theory by means of observations of objects in the solar system. These tests include an examination of the principle of equivalence (POE), the Shapiro delay, the advances of planetary perihelia, the possibility of a secular variation $\dot{G}$ in the "gravitational constant" G, and the rate of the de Sitter (geodetic) precession of the Earth-Moon system. Our current results in these tests are consistent with the predictions of general relativity (GR), and we obtain the following standard deviations for the relevant parameters: 1×10^{-2} for the fractional relativistic contribution to the perihelion advance of Mercury, 1×10^{-3} for Nordtvedt's η parameter quantifying a putative POE violation, 2×10^{-2} for the metric parameter β, 2×10^{-3} for the metric parameter γ, and $1 \times 10^{-11} yr^{-1}$ for $\dot{G}/G$. These standard deviations represent our estimate of the true uncertainties in the parameter values derived from the data analysis, not merely the statistical uncertainties from the least-squares fits. These results are consistent with our preliminary results focusing on the contribution of lunar laser ranging (LLR), which were presented at the seventh Marcel Grossmann meeting on general relativity (Chandler et al. 1996). The largest improvement over previous results comes in the uncertainty for η: a factor of five better than our previous value (Chandler et al. 1990). This improvement reflects the increasing strength of the LLR data. A similar analysis presented at the same meeting by a group at the Jet Propulsion Laboratory gave a similar result for η (Williams et al. 1996). Our value for β represents our first such result determined simultaneously with the solar quadrupole moment from the dynamical data set. These results are being prepared for publication.

Our work has also borne fruit in related areas. The POE test through the behavior of Earth-borne clocks requires a knowledge of the relative coordinates of those clocks and the sources of the reference timing signals (in our case, distant pulsars), since the usual technique of deducing those coordinates from analysis of the timing signals assumes the validity of POE. The necessary independent information on the pulsar positions (from VLBI observations of the pulsars) provides an opportunity to tie together the reference frame of the extragalactic radio sources and that of the planetary ephemerides. Together with our colleague N. Bartel, we have shown how positions determined from different planetary ephemerides can be compared (a long-standing problem in the field of pulsar timing) and how the combination of VLBI and pulse timing information can yield a direct tie between planetary and radio frames (Bartel et al. 1996).

We have continued to include new data in our analysis as they became available, primarily from the ongoing programs of lunar laser ranging and planetary radar ranging, editing the data to remove or correct "blunder" points as needed. The accumulation of LLR data, in particular, has increased the power of that data set such that it now outweighs the planetary data in our studies of the possible secular variation of G. However, that situation may be about to change, since the Mars Pathfinder is now providing a new series of high-precision ranging measurements between Earth stations and a fixed point on Mars. We expect to gain access to these data in due course. When combined with the existing Mars ranging data from the Mariner 9 and Viking missions, these data will provide a dramatic increase in the sensitivity to a variation of G through the orbits of Mars and Earth. We have performed a sensitivity study in which we assumed round-trip delay measurements with uncertainties of 20 ns would be obtained at a rate of 150 per week for the first thirty days of the Pathfinder mission and 40 per week thereafter, as expected from the mission. The study shows a decrease by about a factor of two in the statistical standard deviation of our estimate of $\dot{G}$ after the addition of five months of Pathfinder tracking data on that schedule. Such an improvement, along with the extended time base of high-precision observations, should have an important contribution in separating out the perturbations of the Earth and Mars orbits due to asteroids from the secular effect of a non-zero $\dot{G}$, thus bringing the effective standard deviation in our $\dot{G}$ estimate closer to the purely statistical one. Achieving a result significantly below $10^{-11} yr^{-1}$ will be an important contribution to the understanding of cosmology, partly in view of the uncertainty in interpreting the Hubble constant H_0 in terms of the age of the universe.

Finally, we have made improvements in our analysis software (PEP) and ported it to a network of modern workstations from its former home on a "mainframe" computer.

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